Environ Monit Assess (2009) 153:339–349
DOI 10.1007/s10661-008-0360-0

Analysis of the changes of vegetation coverage of western Beijing mountainous areas using remote sensing and GIS

Liangyun Liu · Xia Jing · Jihua Wang · Chunjiang Zhao

Received: 4 December 2007 / Accepted: 14 April 2008 / Published online: 31 May 2008

Abstract Mentougou District acts as a crucial component in the ecological buffer in western Beijing mountainous areas, Beijing, China. Using two Landsat MSS/TM images acquired on July 14, 1979 and July 23, 2005, the vegetation coverage of Mentougou District was calculated based on normalized difference vegetation index and spectral mixture analysis (NDVI-SMA) model. Its temporal and spatial changes were analyzed according to digital elevation model (DEM) image, social and economic data. The results showed that the vegetation coverage decreased from 76.4% in 1979 to 72.7% in 2005. Vegetation degradation was probably the result of human disturbance, such as outspreading of resident areas, and coal and stone mining activities, while vegetation restoration might be contributed by the combined effects of both natural processes and ecological construction effort. Vegetation changes were closely related to topographical characteristics. Plants at high altitude were more stable and less degraded than the plants at low altitude, while the plants on steep slope or northwest aspect were more vulnerable to degradation. During the period of 26 years, landscape appeared to become more fragmental, and ecological quality of the land seemed deteriorated sharply in that highly-covered vegetation area has been decreased by 24%.

Keywords Coverage · Remote sensing · Vegetation degradation · Ecological restoration · DEM

L. Liu · X. Jing · J. Wang · C. Zhao
National Engineering Research Center for Information Technology in Agriculture,
P. O. Box 2449 #26, Beijing 100097, China

L. Liu (✉)
Center for Earth Observation and Digital Earth,
CAS, Kedian Tower F14, No.9 Beiyitiao Road,
Zhongguancun Haidian District,
Beijing 100190, China
e-mail: liuliangyun@sina.com

Introduction

Estimation of vegetation properties with remotely-sensed imagery technology has become quite reliable and successful. Many methods have been developed to predict vegetation coverage information from multi-spectral remote sensing images, and these methods include vegetation indices (Choudhury et al. 1994; Toby and David 1997, Boyd et al. 2002), multiple regression (Graetz et al. 1988; Boyd et al. 2002; Peter 2002), classification decision tree (Hansen et al. 2002), and spectral mixture analysis (SMA) (Pech et al. 1986; Leprieur et al. 1994; Gutman and Ignatov 1998; Qi et al. 2000; Xiao and Moody 2005).

Spectral mixture analysis can be used to estimate sub-pixel canopy proportions from multi-spectral satellite data. Good results have been achieved using models with two, three, or four endmembers (Xiao and Moody 2005). Normalized difference vegetation index (NDVI) in combination with SMA is the simplest model in the linear mixing models, which assumes that the pixel is only composed of vegetation and bare soil (Xiao and Moody 2005). Based on NDVI-SMA model, Leprieur et al. (1994) successfully monitored the vegetation coverage in Sahelian region from SPOT. Qi et al. (2000) found that the remotely sensed vegetation coverage information was still fairly reliable even without atmospheric correction.

Multi-temporal satellite images were also adopted to monitor vegetation coverage and its yearly or seasonal variations (Qi et al. 2000; Vasconcelos et al. 2002; Guerschman et al. 2003). However, few researchers have linked temporal and spatial variations of vegetation coverage with terrain data, such as altitude, slope and aspect. Because plant function types and their variations under natural condition are determined by topographical conditions at regional scale, it is difficult to identify the driving force (human disturbance or natural processes) of the vegetation variation, and therefore almost impossible to make appropriate ecological restoration decisions at pixel scale.

Mentougou District is located in the west of Beijing city, and it plays a critical role as an ecologic buffer for Beijing, which is often suffered from abominable climate and environmental events. According to functional orientation program for districts in Beijing, Mentougou will serves as an ecological conservancy district from a mining area in the west of Beijing. Therefore, in the process of ecological restoration, it is crucial to understand the status of vegetation coverage and temporal and spatial variations in the mountainous areas of western Beijing.

The aims of this study are: (1) to investigate the vegetation coverage of Mentougou District using two Landsat MSS/TM images, acquired on July 14, 1979 and July 23, 2005; (2) to analyze the characteristics of vegetation variation with altitude, slope and aspect, and to identify the key driving factors (natural processes or human disturbance) of the vegetation variation at pixel scale; (3) to provide recommendation for ecological restoration in the construction of ecological wall in western Beijing.

Study area and data

Study area

Mentougou District is located in the west of Beijing city (115°25′–116°10′ E, 39°48′–40°1′3 N). It lies in a transitional land between North China Plain and Mongolia Altiplano, where the topography is higher in the northwest and lower in the southeast. In the district, 98.5% of the area is mountainous area, leaving only 1.5% as plain land.

Mentougou District belongs to continental monsoon climate with droughty and windy spring, sweltering and rainy summer, cool and humid autumn, and cold and dry winter. The climate in the west mountain is quite different from that in the east plain. The average annual temperature is 11.7°C in the east plain, and 10.2°C in the west mountain. Rainfall generally decreases from east to west. Affected by the instability of atmospheric circulation and sea wind, annual rainfall varies from 900 to 400 mm. Figure 1 shows the map of Mentougou and the study area.

Data acquisition

DEM data The DEM data with a spatial resolution of 30 m were converted from digital contours of Mentougou District at scale of 1:10,000. The slope and aspect of the district were calculated based on the DEM data, which, along with slope and aspect data, clearly depicts Mentougou's topographical characteristics.

Image acquisition Two selected Landsat MSS/TM images of Mentougou were acquired on July 14, 1979 and July 23, 2005, and both were cloud-free. Because both images were acquired in the same month of July with only 9 days apart, the vegetation growth and coverage should be presumably comparable. Therefore, these two images can be used to monitor the dynamic changes of vegetation coverage in Mentougou district spatially and temporally.

Precipitation According to the phenology of Beijing area, vegetation cover reaches its peak, and stays in a stable status through July. However, precipitation affects the vegetation coverage, especially in dry years. Considering the precipitation has its lag effect on vegetation growth, the precipitation data between January to July from 1979 to 2005 were analyzed. The first semiannual precipitation rates were 170.2 mm for the year of 1979 and 163.5 mm for the year of 2005. The average value was about 150 mm. Therefore, the vegetation coverage revealed by these two satellite images can reflect the vegetation variation from 1979 to 2005, and the effect of precipitation on vegetation growth in these two periods can be neglected.

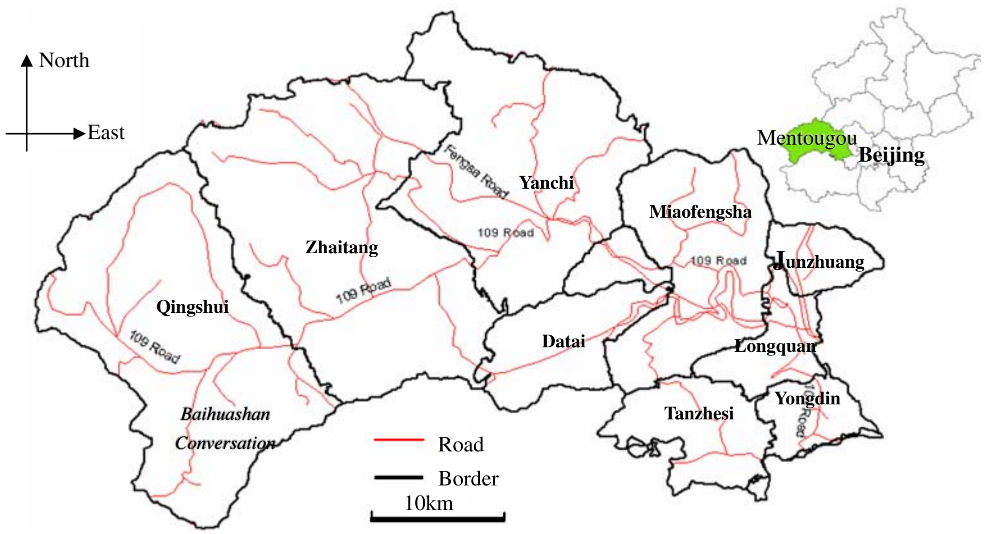

Fig. 1 Municipal villages and roads of Mentougou District

Satellite image preprocessing

Image geometric correction

Landsat TM image acquired on July 23, 2005 was geometrically corrected based on the 1:10,000 digitized raster map. The digitized raster map was set as the base image, and there were about 50 ground control points (GCPs) selected using Envi 4.2 software. The Landsat TM image was warped using the third-degree polynomial model, and the Landsat TM image was linearly re-sampled with a resolution of 30 m. The geometric correction precision was better than half pixel, with RMS errors of 9.9 m in longitude direction and 10.8 m in latitude direction.

The Landsta MSS image acquired on July 23, 2005 was then geo-referenced to the Landsat TM image. The geo-corrected Landsat TM image was set as the base image, and there were about 100 uniformly distributed GCPs selected using Envi 4.2 software. The Landsat MSS image was warped using the Delaunay Triangulation method (Delaunay triangulation warping fits triangles to the irregularly spaced GCPs and interpolates values to the output grid), and the Landsat MSS image was linearly re-sampled with a resolution of 30 m. The geometric correction precision was better than one pixel, with RMS errors of 23.5 m in longitude direction and 17.3 m in latitude direction.

Image radiometric calibration

Firstly, the empirical line (EL) calibration method was employed for atmospheric correction for the TM image on July 23, 2005, and the TM image was then converted from digital number to reflectance (Farrand et al. 1994). Secondly, the pseudo invariant objects, such as water, bare soil, dam, dense vegetation, were selected from the two Landsat TM/MSS images. Finally, the MSS image on July 14, 1979 was matched to the TM image on July 23, 2005 using the least square regression method, and the MSS image was also converted from DN value to reflectance.

Monitoring the vegetation coverage using NDVI-SMA model

NDVI-SMA model

The assumption of NDVI-SMA is that NDVI value of a given pixel is a linear combination of NDVI values of green vegetation and bare soil, weighted by their relative proportions. Qi et al. (2000) found that NDVI-SMA was not sensitive to the image radiometric correction, and could be employed to estimate vegetation coverage even without atmospheric correction.

Assuming that a pixel signal consists of contributions from two components: soil and vegetation. if fractional green vegetation cover is f_c the fractional soil cover should be $1-f_c$. Therefore, the resulting signal, S, as observed by a remote sensor can be expressed as

$$S = f_c \times S_v + (1 - f_c) \times S_s \quad (1)$$

where S_v is the signal contribution from the green vegetation component and S_s is from the soil component.

Equation 1 is applicable to remotely sensed data in the reflectance domain (Maas 1998) and spectral vegetation index domain (Leprieur et al. 1994). When applied with a spectral vegetation index such as NDVI, Eq. 1 may be approximated into

$$\mathrm{NDVI} = f_c \times \mathrm{NDVI_{veg}} + (1 - f_c) \times \mathrm{NDVI_{soil}} \quad (2)$$

which can be further re-formulated as

$$f_c = (\mathrm{NDVI} - \mathrm{NDVI_{soil}}) / (\mathrm{NDVI_{veg}} - S_{soil}) \quad (3)$$

where $\mathrm{NDVI_{soil}}$ is the NDVI value of a bare soil area, and $\mathrm{NDVI_{veg}}$ is the NDVI value of a pure vegetation area.

When Eq. 3 is adopted to calculate the coverage of Mentougou, $\mathrm{NDVI_{soil}}$ and $\mathrm{NDVI_{veg}}$ must be set. Firstly, NDVI data of the image was calculated, and the histogram of NDVI data was derived. Secondly, NDVI value that accounted for 1% pixel of the histogram was set as $\mathrm{NDVI_{soil}}$, and the NDVI value for 99% pixel was set as $\mathrm{NDVI_{Veg}}$. Finally, the $\mathrm{NDVI_{soil}}$ and $\mathrm{NDVI_{Veg}}$ values were put into Eq. 3, and the coverage image was calculated, where the pixels with negative value were set as 0, and the pixels with values larger than 1 were set as 1.

Validation of NDVI-SMA model

The validation experiment was carried out on June 30, 2006. Because it was difficult to find and investigate the ground-truth plots for this rugged area in Mentougou District, only 17 relatively uniform and flat plots with different plant types were selected. The coverage of each plot was surveyed by visual estimation (Zhou et al. 1998), and the remotely sensed coverage of each plot was extracted from the coverage image in 2005 according to its location determined by a global position system (GPS). Table 1 lists the data of the 17 investigated plots.

Figure 2 illustrates the statistical scatter plot of the surveyed and remotely sensed coverage data. The result indicate that the coverage from NDVI-SMA model was significantly correlated to the values from visual survey with a coefficient of 0.558 (R^2) and a RMSE of 0.12. Because of the low number of ground-truth plots, it should be cautious to directly apply the statistical model built from data in Table 1.

Table 1 The information of 17 ground-investigated plots for coverage

GPS no.	Lat	Long	Surveyed coverage	RS coverage	Plant type
46	39.9841	116.0528	0.60	0.53	Shrubbery
52	40.0337	115.8493	0.30	0.37	Shrubbery
53	40.0200	115.8646	0.80	0.73	conifer and shrub
54	40.0210	115.8692	0.50	0.47	Shrubbery
55	40.0409	115.8588	0.60	0.59	Shrubbery
56	40.0648	115.8543	0.60	0.53	Shrubbery
HF1	40.0283	115.9941	0.50	0.63	Shrubbery
HF2	39.9291	116.0870	0.50	0.39	Conifer
HF3	39.9765	116.0671	0.70	0.65	Shrubbery
HF7	40.0089	115.9989	0.70	0.69	Shrubbery
HF8	40.0091	115.9926	0.70	0.65	Conifer and shrub
HF9	40.0041	115.9880	0.90	0.77	Arbor
HF10	40.0081	115.9393	0.50	0.62	Arbor and shrub
HF11	40.0049	115.9737	0.80	0.732	Arbor and shrub
HF13	40.0733	115.8569	0.40	0.58	Shrubbery
HF14	39.9832	116.0528	0.70	0.504	Shrubbery
HF12	40.0079	115.5198	1.00	0.97	Arbor

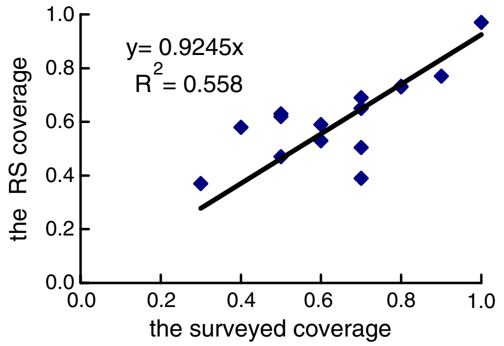

Fig. 2 The relation between remotely-sensed coverage determined by sub-pixel model and the coverage by ground visual estimation

In addition, the vegetation coverage can be measured by optical imaging method for the homogenous flat forest area (Chen and Cihlar 1995). However, in rugged area, the reliability is questionable for some field survey methods in measuring the vegetation coverage of forest (Curran and Williamson 1986; Wilson et al. 1987; Zhou et al. 1998). Besides the sample size issues outlined by Curran and Williamson (1986), it was also argued that some field methods could produce significantly inconsistent results, making the subsequent processing of remotely sensed data a less-meaningful effort. Wilson et al. (1987) summarized the limitations and disadvantages of various field techniques. For example, in rugged areas, it became quite uncertain to examine and validate the remotely sensed result based on field methods, including visual estimation. Therefore, NDVI-SMA model appeared to be reasonably reliable.

Changes of vegetation coverage of Mentougou

The vegetation coverage changes in Mentougou district

In order to monitor the vegetation coverage using Landsat MSS/TM images, the NDVI images were calculated from the two images acquired on July 14, 1979 and July 23, 2005, and then the vegetation coverage images of Mentougou were also calculated based on NDVI-SMA model described as Eq. 3. The coverage images were showed in Fig. 3. Obviously, the coverage and landscape features had changed greatly from 1979 to 2005. The ecological degradation was evident, the vegetation cover was decreased, and the landscape became more fragmented than before.

Table 2 shows the vegetation coverage of each village of Mentougou district in 1979 as compared to that in 2005. The result indicated evident vegetation degradation in the period of 26 years, and that the vegetation coverage of the district decreased from 76.4% in 1979 to 72.7% in 2005. There was difference in vegetation degradation in these villages. As a result of increasing residential area and sand/stone disturbance, the vegetation degradation in Yongding, Longquan, Tanzhesi was the most serious.

However, Junzhuang was the only village experienced 5% increase in vegetation coverage, and this was probably due to a great increase of orchard areas. Junzhuang is the traditional area that produce Beijing white pear, which is well known for its unique taste. More than 300 ha pear orchard had been added into the village in the last 20 years. The degradation of vegetation area in four middle villages, Miaofengshan, Wangping, Datai and Zhaitang, was mainly due to human and industry activities, such as quarry and mining. Furthermore, goaf and subsidence region produced by mining activities was increased by 30 km^2 in the last 26 years in these four villages. The degradation in two west villages, Yanchi and Qingshui, was relatively insignificant, and the degradation was due to the conjunct effect of human disturbance and natural degradation, including soil erosion and the decrease of annual rainfall in last 20 years.

In order to quantitatively analyze vegetation degradation, the coverage image in 2005 was subtracted by the image in 1979, and the degradation image was calculated. According to the classification standard for vegetation degradation shown in Table 3, the vegetation degradation image was illustrated as Fig. 4.

From Fig. 4, we found following observations. (1) The vegetation coverage of Mentougou District was relatively steady in general. About 82% of the whole area had less than 15% variation in the coverage. (2) The regions of vegetation degradation were mainly in three southeastern villages, Yongding, Longquan, Tanzhesi, mostly due to the outspreading of resident areas and coal or stone mining industries. Among them, the large degraded region in Miaofengshan due to stone mining was particularly striking and signif-

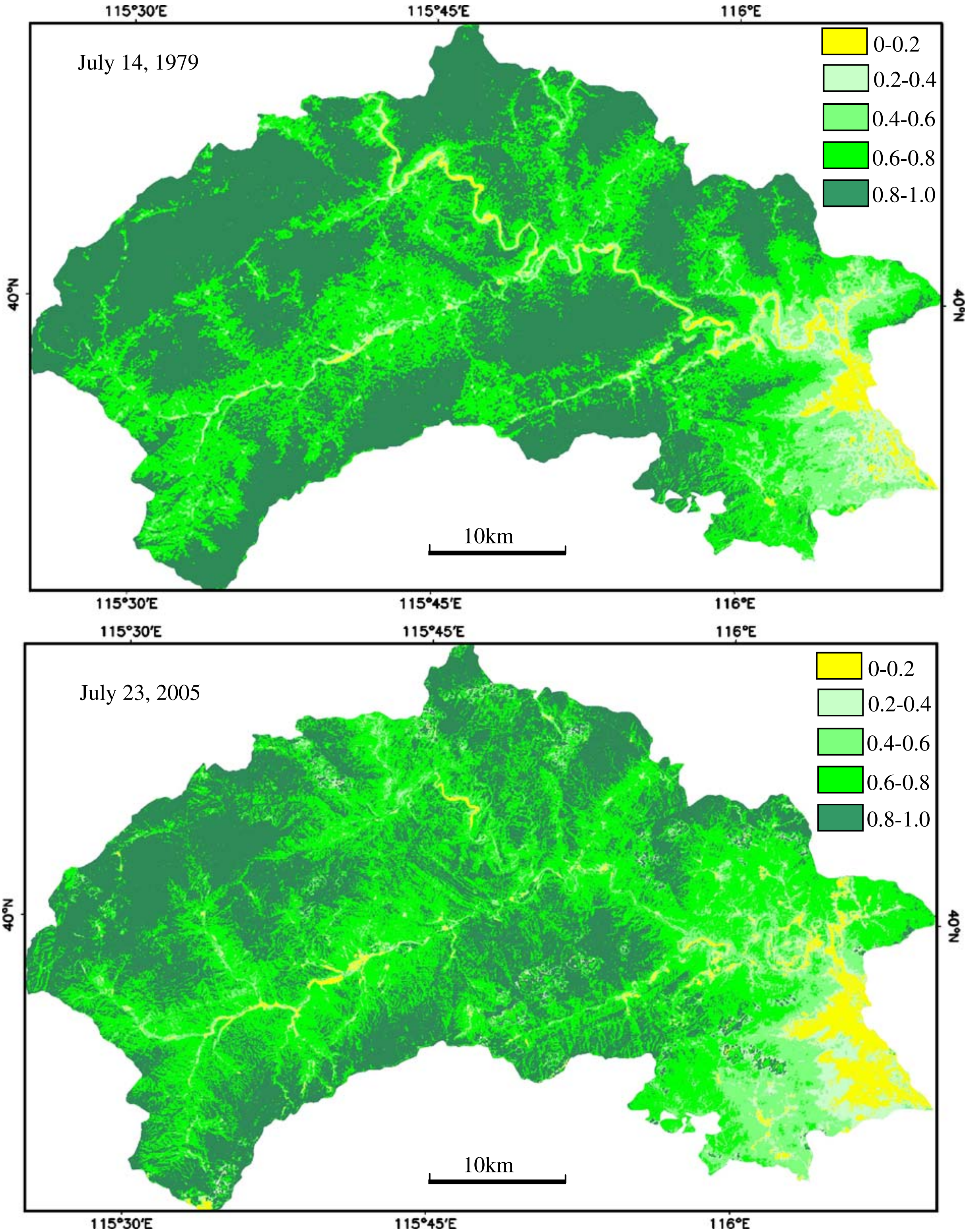

Fig. 3 The coverage images of Mentougou in 1979 and 2005

Table 2 Vegetation coverage changes for different villages of Mentougou District

Village	Area (km^2)	Coverage in 2005 (%)	Coverage in 1979 (%)	Change (%)
Yongding	39.1	23.54	38.10	14.56
Longquan	47.8	34.17	41.10	6.93
Tanzhesi	77.9	56.59	71.02	14.43
Junzhuang	34.3	60.57	56.82	−3.75
Miaofengshan	162.1	68.01	72.39	4.38
Wangping	24.1	74.15	79.55	5.4
Datai	81.0	77.67	81.85	4.18
Zhaitang	377.9	77.72	80.53	2.81
Yanchi	262.5	78.20	79.03	0.83
Qingshui	333.8	80.13	83.04	2.91
Average		72.74	76.42	3.68

icant. Finally, some degraded regions were the result of agricultural and tourism activities along national highway 109, and these regions included western villages, Yanchi, Zhaitang and Qingshui. (3) Spatial characteristics of the vegetation restoration region are also noticeable from Fig. 4. Firstly, there were ecological restoration belts along the national highway 109 in the eastern villages and along the Fengsa Road in Yanchi village, indicating that the efforts of tree plantation in those regions were effective. Secondly, some ecological restoration segments appeared in Junzhuang village due to rapid increase of orchard. Finally, the construction of natural conservation in Baihuashan had also achieved greatly. Because of ecological trans-migrantion, the plants in the conservation were restored mainly by natural process.

Topographical features of vegetation change in Mentougou district

Altitude, slope and aspect can directly or indirectly reflect the spatial difference between natural resources, such as the frequency of artificial activities, light, temperature, rainfall and soil erosion. Therefore, it is common that the changes of vegetation coverage are closely related to topographical conditions. In this study, the vegetation coverage changes were correlated with the altitude, slope and aspect to analyze the driving factors of the changes.

Table 4 shows the relation between the vegetation coverage changes and altitude. The results indicated a relative stable vegetation coverage in high altitude, and low probability of degradation and restoration. In contrary, the vegetation degradation in low altitude was more severe, and the probability of the vegetation degradation and restoration was also relatively high. These topographical characteristics agreed with the fact that more serious human disturbance occurred in low altitude (<400 m) rather than in high altitude. Therefore, these results imply that the vegetation coverage under natural state might be relatively steady, and that the area with serious vegetation degradation might be mainly the results of human activities, such as development of residential buildings and industries of stone, ore and sand mining.

The statistical relation between vegetation coverage changes and slope suggested that plants were much more vulnerable in the areas with high slope (Table 5). The higher the slope, the lower the probability of vegetation restoration. Interestingly, although human activities are more likely to happen in the area with low slope, the probabilities of vegetation degradation and restoration are actually much higher than the other areas. When the slope was

Table 3 Classification standard for vegetation degradation

	Serious Degradation (SD)	Degradation (D)	Light Degradation (LD)	Steady (S)	Light Restoration (LR)	Restoration (R)	Full Restoration (FR)
Coverage difference	>30%	15~30%	5~15%	±5%	−15~−5%	−30~−15%	<−30%

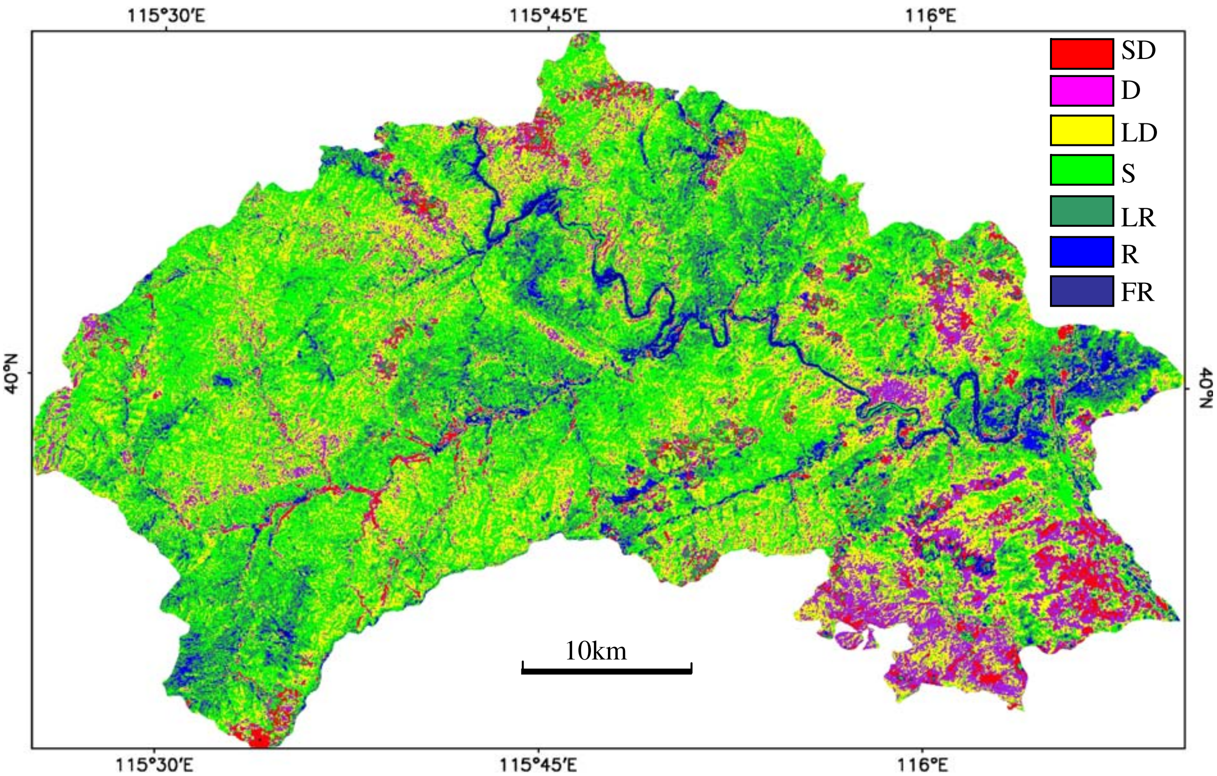

Fig. 4 The vegetation degradation of Mentougou from 1979 to 2005

higher than 20°, the lower the slope, the greater the probability of vegetation restoration. Unfortunately, the probability of serious degradation (coverage was decreased by more than 15%) increases with slope, suggesting that the restoration of degraded vegetation in areas with a high slope was more difficult. Natural restoration process of the degraded vegetation in high slope is normally lengthy, ineffective, and even infeasible because the decrease of vegetation coverage at high slope area often results in severe soil erosion and serious ecological disturbance for a long time. Therefore, the limit ability of ecological construction must be considered with soil erosion, especially for the degraded region with high slope.

Aspect determines the natural environmental condition such as illumination, and has profound influence on temperature and humidity. It is very important to analyze the relationship between aspect and vegetation degradation of Mentougou. In the study, the aspect was averaged into 12 grades from 0–360°

Table 4 The relationship between vegetation degradation and DEM

The percentage of different degradation and restoration in the same altitude level (%)						
Altitude(m)	<200	200–400	400–800	800–1200	1200–1600	>1600
SD	10.61	3.87	2.07	2.39	2.12	2.77
D	21.92	17.35	9.25	7.92	5.92	7.04
LD	19.16	24.46	26.19	30.50	31.32	13.00
S	20.17	26.93	43.49	43.81	54.07	63.52
LR	13.32	15.35	16.03	13.17	5.97	13.27
R	10.99	7.95	2.59	2.05	0.58	0.40
FR	3.83	4.09	0.38	0.16	0.03	0.00
Total	100	100	100	100	100	100

Table 5 The relationship between vegetation degradation and slope

The percentage of different vegetation degradation and restoration at the same slope level (%)							
Slope_6C	0–5	5–10	10–20	20–30	30–40	40–50	>50
SD	9.61	4.41	2.51	1.84	2.12	2.87	5.39
D	17.45	11.75	9.07	7.58	9.27	15.65	23.02
LD	17.98	20.04	20.73	24.70	33.10	39.80	36.81
S	24.49	34.99	42.21	46.82	44.17	34.61	26.25
LR	13.70	19.16	19.89	15.96	9.69	5.79	6.60
R	10.35	7.47	4.73	2.68	1.42	0.96	1.57
FR	6.42	2.18	0.86	0.41	0.22	0.31	0.37
Total	100	100	100	100	100	100	100

and denoted by A01–A12, where A01, A12 was the north slope (shady slope), A06, A07 was the south slope (sunny slope), A03, A04 was the east slope, and A09, A10 was the west slope. Table 6 illustrated the statistical relation between vegetation coverage changes and aspect data.

From Table 6, it can be concluded that vegetation degradation in Mentougou District varies with aspect.

1. The vegetation coverage is relatively low in sunny slopes, and high in the shady slopes.
2. The vegetation degradation is more serious at northwest slopes than southeast slopes. Compared with southeast slope, northwest monsoon in winter and spring of Beijing can be quite harsh for plants at northwest aspect. In addition, rainfall varies greatly from east to west, with more rainfall in the southeast than the northwest. Finally, the fierce radiation in afternoon at the west slope increases evaporation. Therefore, little precipitation and high evaporation on the west slope result in little water available for plant growth.
3. The probability of vegetation restoration is higher at the southeast slope than that at the northwest slope, indicating that the vegetation at northwest slope is more vulnerable and less likely to be restored.

Changes of vegetation landscape in Mentougou district

Vegetation landscape pattern is the product of long-term conjunct action of human disturbance and natural processes. Spatial configuration and composition of landscape elements play an important role in ecological functionality and biological diversity.

The area of each patch comprises a landscape mosaic, and can be perhaps the single most important and useful piece of information of landscape. Not

Table 6 The relationship between vegetation degradation and aspect

	Plain	A01	A02	A03	A04	A05	A06	A07	A08	A09	A10	A11	A12
The coverage at each aspect level													
Area (%)	2.14	7.79	8.87	8.43	9.07	9.52	8.07	7.34	7.94	7.28	7.68	8.00	7.87
Cov2005 (%)	36.9	74.8	74.9	75.3	72.3	71.5	72.6	73.1	72.7	73.5	73.6	73.6	73.3
Cov1979 (%)	38.7	78.8	77.4	76.9	74.1	73.3	74.7	76.5	77.2	78.8	79.7	79.9	78.8
The percentage of different vegetation degradation and restoration at the same aspect level (%)													
SD	9.9	2.5	2.4	2.2	2.9	2.7	2.2	2.6	3.0	2.8	3.2	3.2	3.0
D	16.8	10.0	8.2	7.3	8.1	8.6	8.5	10.0	11.0	11.9	12.9	13.6	12.3
LD	16.3	29.0	23.2	20.4	20.4	20.9	22.7	25.7	29.2	33.2	35.7	36.6	34.1
S	22.4	42.8	46.8	48.1	45.4	43.7	44.0	42.7	41.2	38.8	36.3	34.8	37.1
LR	14.1	12.3	15.1	17.5	17.7	18.5	17.8	15.5	12.6	10.6	9.3	8.7	10.1
R	12.6	2.7	3.3	3.6	4.2	4.4	3.9	3.0	2.6	2.3	2.2	2.3	2.7
FR	7.9	0.7	1.0	1.0	1.2	1.2	0.8	0.4	0.5	0.4	0.5	0.7	0.7

only is this information the basis for many of the patches, classes, and landscape indices, but the patch area itself has a great deal of ecological utility. For example, there is considerable evidence that the diversity of bird species (richness, occurrence and abundance of some species) is strongly correlated with patch size (Robbins et al. 1989). Most species have minimum area requirements, the minimum area needed to meet all life historical requirements. Similarly, the size and number of patches comprising a class or the entire landscape mosaic is perhaps the most basic aspect of landscape pattern that can affect myriad processes.

Therefore, six landscape indices, including patch number, average patch area, mid, largest, and minimum patch area, were calculated for each coverage level in 1979 and 2005. The results were illustrated in Table 7.

From Table 7, we summarize following conclusions.

1. Landscape fragmentation had increased sharply over the period of 26 years. At each coverage level, the landscape fragmentation in 1979 generally demonstrated fewer patches, larger average patch size, longer average edge length, and lower average edge density than those in 2005. However, in consideration of the different spatial resolution of the two Landsat TM/MSS images, the increase of the landscape fragmentation from 1979 to 2005 might be overstated.
2. The ecological quality of the landscape had notably degraded. The landscape area in 1979 was smaller than that in 2005 for the four landscape types with coverage smaller than 0.8. However, for the landscape type with coverage larger than 0.8, the landscape area in 1979 was greater than that in 2005. Therefore, the landscape area for the full-coverage landscape type was decreased by an average of 24% from 1979 to 2005, and the rapid reduction of full-covered regions was even more significant if it is compared with the average decrease of vegetation coverage in Mentougou district.

Conclusions

The coverage of Mentougou District was calculated based on NDVI–SMA model from the two satellite images acquired on July 14, 1979 and July 23, 2005, and the coverage was decreased from 76.4% in 1979 to 72.7% in 2005.

The temporal and spatial changes of vegetation coverage were also linked to DEM data, social and economical data. The vegetation changes were closely related to topographical features. The vegetation degradation in low altitude appeared to be more serious than that in high altitude. The plants in steep slope or northwest aspect were more vulnerable, and their vegetation degradation was more severe than the plants in flat slope or southeast aspect.

The vegetation landscape in Mentougou District became more fragmental from 1979 to 2005, attested

Table 7 The landscape area of vegetation coverage in 1979 and 2005

Coverage and landscape type		Year	Landscape area	Patch number	Average patch area	Largest patch index	Minimal patch index	Average edge length	Edge density
0–0.2	Non coverage	1979	29,094,775	0.3727	576.3	291	99,982	1,340	2.70E−04
		2005	48,690,793	0.6522	576.3	652	74,679	837	3.80E−04
0.2–0.4	Low coverage	1979	49,035,566	0.3155	576.3	1,038	47,240	926	6.60E−04
		2005	49,779,388	0.3199	576.3	2,834	17,565	446	8.70E−04
0.4–0.6	Middling coverage	1979	1.12E+08	0.3290	576.3	1,742	64,211	1,036	1.20E−03
		2005	1.38E+08	0.5093	576.3	4,822	28,631	563	1.90E−03
0.6–0.8	Higher coverage	1979	4.97E+08	0.6085	576.3	2,044	243,166	2,273	3.20E−03
		2005	6.02E+08	0.7979	576.3	4,521	133,256	1,531	4.80E−03
0.8–1.0	Full coverage	1979	7.6E+08	0.3429	576.3	1,873	405,990	1,883	2.40E−03
		2005	6.08E+08	0.3274	576.3	3,445	176,620	1,551	3.70E−03
0–1.0	Landscape	1979	1.45E+09	0.2090	576.3	6,988	207,132	1,621	7.80E−03
		2005	1.45E+09	0.3321	576.3	16,274	88,942	1,032	1.20E−02

by sharply deteriorated ecological quality and 24% decrease of highly-covered vegetation area. This rapid reduction of full-covered regions was particular concerned if it is compared with the average decrease of vegetation coverage in Mentougou district.

Acknowledgements The authors gratefully acknowledge the financial support provided for this research by Beijing Science Foundation, China (4071002, 4061002) and Natural Science Foundation, China (40771134).

References

Boyd, D. S., Foody, G. M., & Ripple, W. J. (2002). Evaluation of approaches for forest cover estimation in the Pacific Northwest, USA, using remote sensing. *Applied Geography*, *22*, 375–392.

Chen, J. M., & Cihlar, J. (1995). Plant canopy gap size analysis theory for improving optical measurements of leaf area index of plant canopies. *Applied Optics*, *34*(27), 6211–6222.

Choudhury, B. J., Ahmed, N. U., Idso, S. B., Reginato, R. J., & Daughtry, C. (1994). Relations between evaporation coefficients and vegetation indices studied by model simulations. *Remote Sensing of Environment*, *50*, 1–17.

Curran, P. J., & Williamson, H. D. (1986). Sample size for ground and remotely sensed data. *Remote Sensing of Environment*, *20*, 31–41.

Farrand, W. H., Singer, R. B., & Merenyi, E. (1994). Retrieval of apparent surface reflectance from Aviris data – A comparison of empirical line, radiative transfer, and spectral mixture methods. *Remote Sensing of Environment*, *47*, 311–321.

Graetz, R. D., Pech, R. R., & Davis, A. W. (1988). The assessment and monitoring of sparsely vegetated rangelands using calibrated Landsat data. *International Journal of Remote Sensing*, *9*, 1201–1222.

Guerschman, J. P., Paruelo, J. M., Di Bella, C., Giallorenzi, M. C., & Pacin, F. (2003). Land cover classification in the Argentine Pampas using multi-temporal Landsat TM data. *International Journal of Remote Sensing*, *24*, 3381–3402.

Gutman, G., & Ignatov, A. (1998). The derivation of the green vegetation fraction from NOAA/AVHRR data for use in numerical weather prediction models. *International Journal of Remote Sensing*, *19*, 533–543.

Hansen, M. C., DeFries, R. S., Townshend, J. R. G., Sohlberg, R. A., Dimiceli, C., & Carroll, M. (2002). Towards an operational MODIS continuous field of percent tree cover algorithm: Examples using AVHRR and MODIS data. *Remote Sensing of Environment*, *83*, 303–319.

Leprieur, C., Verstraete, M. M., & Pinty, B. (1994). Evaluation of the performance of various vegetation indices to retrieve vegetation cover from AVHRR data. *Remote Sensing Review*, *10*, 265–284.

Maas, S. (1998). Estimating cotton canopy ground cover from remotely sensed scene reflectance. *Agronomy Journal*, *90*, 384–388.

Pech, R. P., Graetz, R. D., & Davis, A. W. (1986). Reflectance modeling and the derivation of vegetation indices for an Australian semiarid shrub land. *International Journal of Remote Sensing*, *7*, 389–403.

Peter, R. J. (2002). North Estimation of fAPAR, LAI, and vegetation fractional cover from ATSR imagery. *Remote Sensing of Environment*, *80*, 114–121.

Qi, J., Marsett, R. C., Moran, M. S., Goodrich, D. C., Heilman, P., Kerr, Y. H., et al. (2000). Spatial and temporal dynamics of vegetation in the San Pedro River basin area. *Agricultural and Forest Meteorology*, *105*, 55–68.

Robbins, C. S., Dawson, D. K., & Dowell, B. A. (1989). Habitat area requirements of breeding forest birds of the Middle Atlantic States. *Wildlife Monographs*, *103*, 1–34.

Toby, N. C., & David, A. R. (1997). On the relation between NDVI, fractional vegetation cover, and leaf area index. *Remote Sensing of Environment*, *62*, 241–252.

Vasconcelos, M. J. P., Mussá Biai, J. C., Araújo, A., & Diniz, M. A. (2002). Land cover change in two protected areas of Guinea-Bissau (1956–1998). *Applied Geography*, *22*, 139–156.

Wilson, A. D., Abraham, N. A., Barratt, R., Choate, J., Green, D. R., Harland, R. J., et al. (1987). Evaluation of methods of assessing vegetation. change in the semi-arid rangelands of southern Australia. *Australian Rangeland Journal*, *9*, 5–13.

Xiao, J., & Moody, A. (2005). A comparison of methods for estimating fractional green vegetation cover within a desert-to-upland transition zone in central New Mexico, USA. *Remote Sensing of Environment*, *98*, 237–250.

Zhou, Q., Robson, M., & Pilesjo, P. (1998). On the ground estimation of vegetation cover in Australian rangelands. *International Journal of Remote Sensing*, *9*, 1815–1820.